# Model to Predict Mine Migration and Related Bedform


Principal Investigator Douglas L. Inman
Integrative Oceanography Division, 0209
Scripps Institution of Oceanography, UCSD
9500 Gilman Dr.
La Jolla, CA 92093-0209
Phone (858) 534-4334 Fax (858) 534-0300 e-mail dli@coast.ucsd.edu

Co-principal Investigator Scott A. Jenkins
Integrative Oceanography Division, 0209
Scripps Institution of Oceanography, UCSD
9500 Gilman Dr.
La Jolla, CA 92093-0209
Phone (858) 534-6480 Fax (858) 534-0300 e-mail saj@coast.ucsd.edu



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## LONG-TERM GOALS

To develop a process-based model for the prediction of mine migration (mine walking); and to use this model to develop general principles of mine migration that can be used by the fleet

## OBJECTIVES

The basic scientific objectives are to determine the leading order forces that induce mine migration and develop a computer code based on the formulation of these forces. Because gravity is obviously among that set of forces, our objective also requires resolution of the local bed slopes as well as the effect on slope of the bedform response to the presence of the mine.

## APPROACH

The following tasks are designed to meet the objectives:

1) Determine a rigorous criteria for the incipient motion that leads to the onset of mine migration.

2) Develop the codes for the migration problem and integrate them into the architecture of the vortex lattice scour/burial (VORTEX) model.

3) Conduct field validation of mine migration prediction during VSW detachment exercises and field experiments off Tampa, FL under the Mine Burial Program.

4) Perform model sensitivity analysis on mine migration and integrate results into the coastal classification system database and a Mine Burial Primer.

# Report Documentation Page

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5) Implement a bedform classification system for parameterizing the slope dependent terms of the incipient motion of the mine.

6) Prepare an improved version of the VORTEX model code for library acceptance with capabilities for predicting mine migration with local bedform dependence.

## WORK COMPLETED

We have researched the literature on mine burial experiments and identified three distinct modes of mine migration that are dependent on both the mine shape and bed sedimentary properties. We have formulated incipient motion criteria for each of these modes. To incorporate these incipient motion algorithms into the VORTEX model, we developed new code for movable local boundary conditions. This new code accounts for changing gravitational slope effects due to the evolution of bedform around the mine. The new codes for migration have undergone preliminary evaluation in field tests during FY2001-02 off Scripps Pier, La Jolla, CA and off the Naval Amphibious Base, San Diego at Silver Strand Beach, CA in FY2002. The Scripps Pier experiments involved the MANTA mine and the MK VII VSW Marker, Type AFD. The Silver Strand Beach experiments were in conjunction with MK VII marine mammal exercises conducted by SPAWAR, Code D352. These experiments have been used to calibrate the model for the dependence of migration on forcing intensity, mine properties (size, weight, shape), and local bedform. Further validation of the model awaits field data from the Mine Burial Program. In the mean time, the present level of validation has led to inclusion of mine migration concepts in the production of a Mine Burial Primer (Inman and Jenkins, 2002). Thus substantial progress has been made in the first year of this effort toward satisfying research objectives (1) through (4) listed above.

## RESULTS

Mine migration is integral to mine burial and is a shape dependent process that varies in direct proportion to the degree of scour. The degree of scour in turn is determined by the intensity of hydrodynamic forcing, the size and weight of the mine, and bed composition and slope. Three modes of migration have been identified: a) scour and roll, b) scour and slip, and c) cohesive bed failure (Figure 1). Mine migration for cylindrical mines and small flat bottom mines migrate by a series of scour and roll events (Figures 1a, 2), whereby the mine successively scours a depression and then rolls or flips into that depression (Inman and Jenkins, 1996). In general, large flat bottom mines (e.g., MANTA, ROCKAN, etc.) migrate by scour and slip sequences (Figure 1b) involving episodic shear failures of the sediment under the mine (Inman and Jenkins, 1997). During shear failure, the mine is in a state of sliding friction with the bed, and is moved by gravity and hydrodynamic forces. On muddy seabeds, migration becomes independent of shape, and depends instead on the strength properties of the bed. When the fluid stress exceeds the cohesive yield stress along a failure plane inside the bed, then the entire slab of bed containing the mine above the failure plane will move as a unit (Figure 1c). Over erosion-resistant beds, waves and currents may cause mines to migrate large distances before scour and burial arrests further mine migration.

Mine migration is governed by Newton's 2$^{nd}$ law and the controlling relations are formulated by balancing the forces due to mine acceleration against the hydrodynamic and gravitational forces acting on it. When the moments of hydrodynamic forces on the bed exceed the gravitational restoring moment on the mine (Figure 3) incipient mine migration results by scour and roll or scour and slip

mechanisms. The threshold criteria for mine migration by cohesive bed failure (Figure 3) is given by formulations for erosional stress (Aijaz and Jenkins, 1994).

Sensitivity analyses with the model and observations from the archival and contemporary field experiments on mine burial have led to the following *rules of thumb* for mine migration:

1. Cylindrical mines will migrate by a scour and roll sequence, during which the axis of the cylinder will align itself parallel to wave crests.

2. The cylindrical mine may move a number of mine diameters in the direction of wave propagation during the burial sequence.

3. Large flat bottom mines (cones and hemispheres) will move less than 1 diameter during a burial sequence. However small hemi-oblate spheroids may flip over and move farther.

***Figure 1. Burial and migration mechanisms: a) nearfield scour and roll, b) nearfield scour and slip, c) cohesive bed failure.***

The change in local bed slope due to scour exerts a strong effect on migration, particularly for the smaller mines as shown in Figure 2. To replicate such complex bedforms, the ground effect formulation of the horseshoe vortex filaments in the model were upgraded from a simple diffusive formulation (Figure 4a) to a shear instability formulation (Figure 4b). This enabled the model to predict repeating interactive bedforms induced by the initial mine disturbance, like those shown in the laboratory experiment by Southard and Dingler, 1971. A filament pair wrap-up, formulation of the

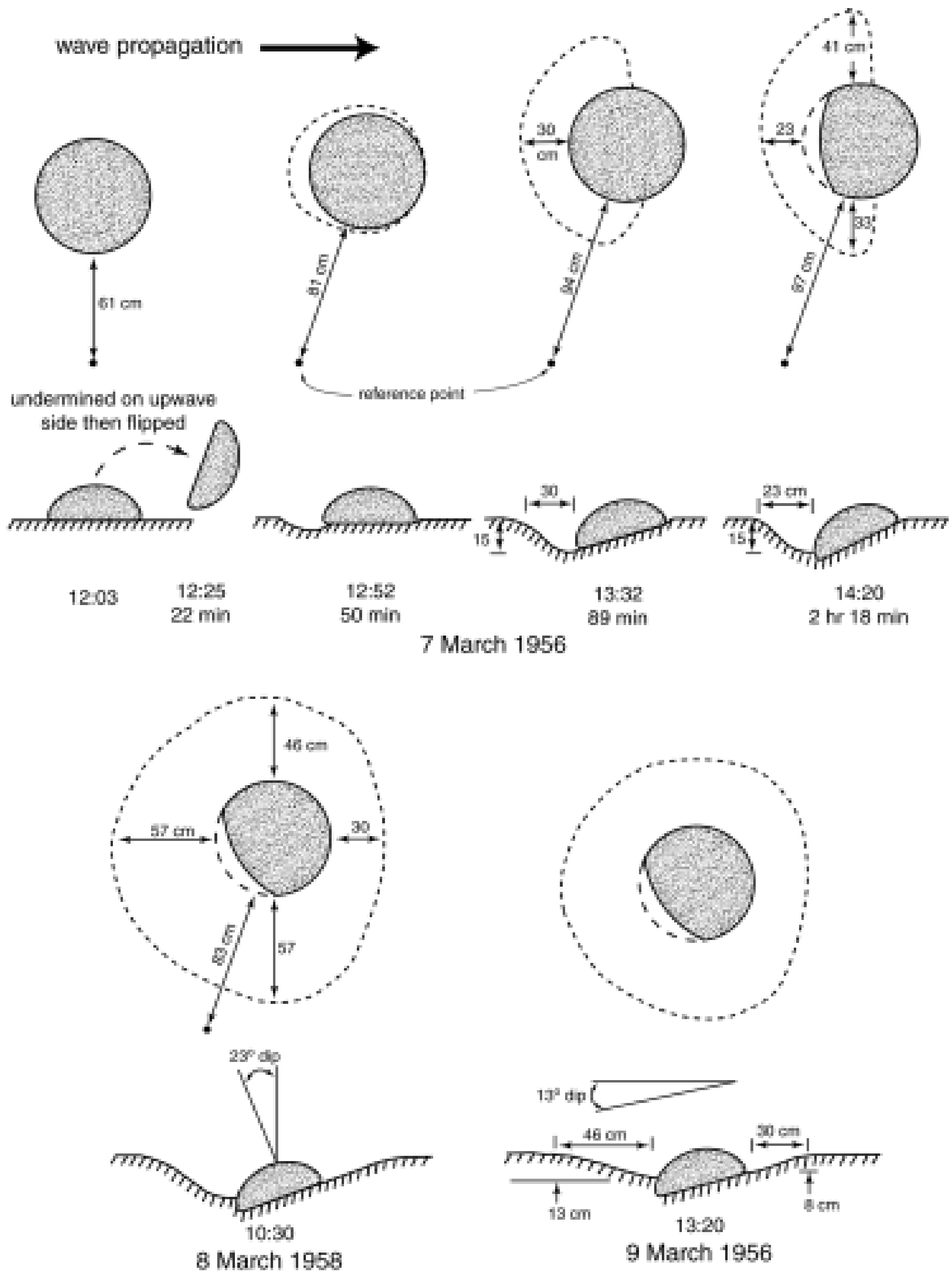
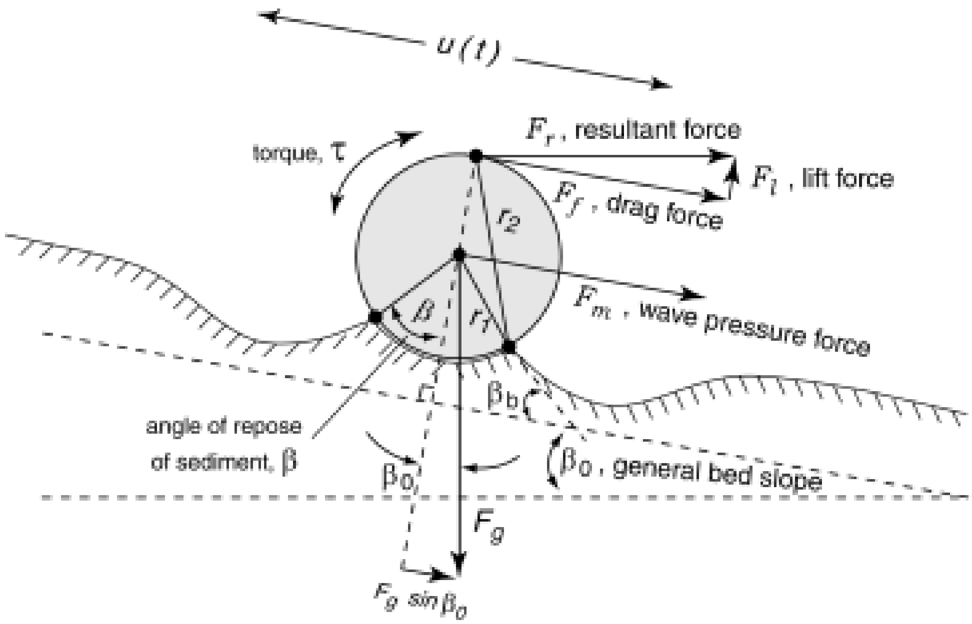



***Figure 2. Scour and burial of a 61 cm diameter hemi-oblate spheroid under wave action in 9 m water depth, total interval ~ 49 hours. [modified from Dill, 1958]***

vortex filaments (Figure 4c) resulted in successful numerical simulations of bedforms around a mine in unidirectional flow (Figure 5) that are similar to those reported in Allen (1984, 1985). Such bedforms undoubtedly have unique acoustic scattering properties important to mine hunting that are different from the indigenous bed roughness.




Threshold of migration criteria: Σ moments = 0

$$\vec{F_g} \times \vec{r_1} = \vec{F_m} \times \vec{r_1} + \vec{F_r} \times \vec{r_2} + \vec{\tau}$$

***Figure 3. Criteria for incipient mine migration. Mine moves when the sum of moments due to hydrodynamic forces (right side of equation) exceed the moment due to gravity (left side of equation).***

## IMPACT/APPLICATIONS

Mine migration is a serious operational concern from both the offensive and defensive standpoint. If migration occurs immediately after deployment, the original mine-lay pattern will be distorted and will not resemble the mine-layers intent. Consequently mine migration may lead to gaps in the mine field that render it ineffective. If mine migration occurs after detection and marking, the mines may move out of neutralization range of counter charges before those charges can be detonated. Hence an apparently cleared mine field may still be dangerous.

Bedform around the mine not only effects mine migration but also controls the bed roughness and acoustic scattering properties of the seabed around the mine, and are consequently important to mine detection. Bedform roughness is an input parameter to the Navy's CASTAR-GRAB Acoustic Prediction Model which ultimately provides mission planners with estimates of the clearance of mine fields.

## TRANSITIONS

Three separate transitions are in progress: a) submission of a draft Mine Burial Primer (Inman and Jenkins, 2002), b) contribution to the "Mine Warfare Environmental Pocket Handbook," and c) provide source code of the Vortex Lattice Model for the Ocean Atmosphere Model Library (OAML).

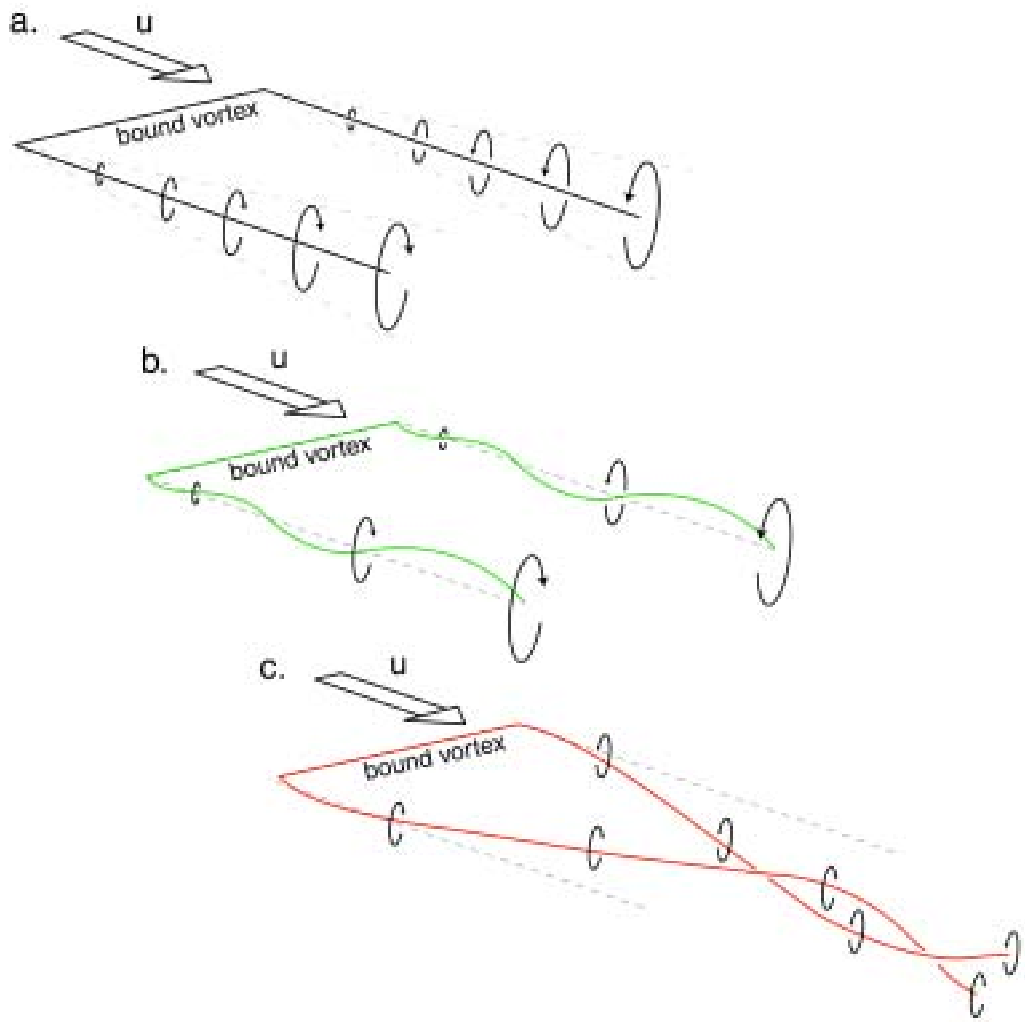



***Figure 4. Ground-effect mechanisms in trailing vortex decay for development of forced and interactive bedforms: a) voticity diffusion [after Peace and Riley, 1983]; b) periodic shear instability of filament pair [after Van Dyke, 1989]; c) interactive filament pair wrap-up [after Althaus, 1991].***

## RELATED PROJECTS

The Vortex Model has been used as a design tool in the development of the VSW Neutralization Marker for the Marine Mammal Systems Branch, SPAWAR, Code D352. The model results for the VSW marker were used in the preparation of the Weapons System Explosive Safety Review Board, WSESRB documents. Sensitivity analysis of the model is being applied to evaluations of new lane

marking concepts by the VSW/MCM detachment at PMS-EOD 7023. VORTEX may also be used to diagnose unexploded ordnance sites (UXO) under a CNO sponsored program directed by the Naval Facilities Engineering Service Center, Code ESC 51, Ocean Engineering, Pt. Hueneme, CA.

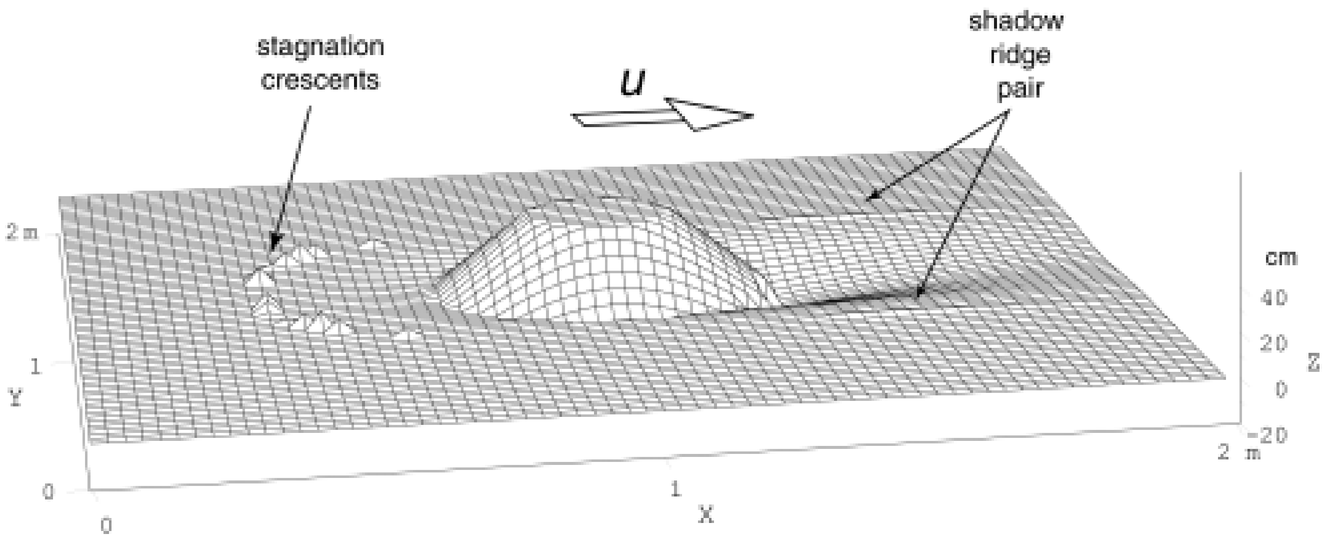



***Figure 5. VORTEX model simulation of MANTA mine buried by unidirectional water flow with associated bedforms; current 40 cm/sec, median grain size 250 mm. [from Jenkins and Inman, 2002]***

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